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Aging Studies of Large Area Proportional Chambers under High-Rate Irradiation with CF_4-based Mixtures (PART 2).

PART 2

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Experimental conditions at the HERA-B experiment impose very strong requirements for gaseous detectors. The charged particle fluxes through the HERA-B tracking system, varying with the radial distance R from the beam line, are about $2 \times 10^7/R^2$ particles per second, and comparable to those that will be encountered by LHC experiments.

The severe radiation environment of the HERA-B experiment leads to a maximum charge deposit on a wire, within the muon detector, of 200 mC/cm per year. We report recent results of aging studies performed by irradiating proportional wire chambers filled with $Ar/CF_4/CH_4$ (74:20:6), $Ar/CF_4/CH_4$ (67:30:3), $Ar/CF_4/CO_2$ (65:30:5), Ar/CF_4 (70:30), CF_4/CH_4 (90:10), CF_4/CH_4 (80:20) mixtures in a three different experimental setups. The size of the irradiation zone varied in the tests from 1 cm up to 500 cm. Our experience shows that the aging rate depends not only on the total collected charge, but, in addition, on the mode of operation and area of irradiation. The possible application of these results to the construction of a large area gaseous detectors for operation in high rate environments is presented.

1 Aging in an Ar/CF_4(70:30) gas mixture

In order to study the influence of materials, cathode cleanliness, and water addition on aging performance we have carried out radiation tests with an Ar/CF_4(70:30) gas, which has very similar transport properties with $Ar/CF_4/CH_4$ (67:30:3) mixture. It is well known that hydrocarbon free mixtures are much more resistant to polymerization effects than gases containing hydrocarbons. The aging results reported in this paper also demonstrate that the lifetime of aluminum proportional chambers changes drastically by replacing 3 % of CH_4 by 5 % of CO_2 in the Ar/CF_4-based mixture. Thus, this difference between aging properties can be solely attributed to the change in the gas phase and gas surface chemical reactions in the wire avalanches, as a result of the removal of CH_4 and addition CO_2 to the mixture. From the viewpoint of plasma polymerization, the main effect of the CF_4 plasma can be shifted from etching to polymer deposition by the addition of H_2 into the plasma and that depending upon the amount of H_2 added to CF_4, the balance between polymerization and ablation can be controlled [22, 23]. It has also been shown that in plasmas the addition of hydrogen or hydrocarbon gases to the CF_4 decreases the F/CF_2 ratio, thus selectively etching SiO_2, while the addition of O_2 or CO_2 increases the F/CF_2 ratio, thereby selectively etching Si [17, 24]. In general, the addition of oxygenated species shifts the chemistry of CF_4 plasmas toward etching while the addition of hydrogenated species shifts the chemistry toward polymerization.

It is also worthwhile to note that in aging studies for the ATLAS muon spectrometer the cathode cleanliness of aluminum proportional chambers was identified as an important factor in influencing the chamber lifetime even in the hydrocarbon free mixture $Ar/CO_2/N_2$ (90:5:5)+1200 ppm H_2O [19]. Hydrocarbon greases from the production process are not always completely removed during the cleaning procedure of the aluminum tubes. In the case of incompletely cleaned tubes, sputtering by UV-photons from wire avalanches can lead to the removal of non-volatile hydrocarbons from the cathode, which then drift and stick to the wires, or can initiate the polymerization processes in

the chamber. Radiation tests with Ar/CF_4, which is expected to have a strong etching capability, can also confirm that aging effects in an $Ar/CF_4/CH_4$ mixture are not initiated by trace contaminants in the gas and appear only when CH_4 is added to Ar/CF_4.

Aging studies with an Ar/CF_4 (70:30) mixture were performed with two tube chamber cells N15,N16, connected in a serial gas flow. A pre-mixed gas was transported to the chamber by stainless steel lines that excluded the presence of H_2O in the gas. The gas flow rate was set to 1.5 l/hour. In order to investigate the influence of photons on aging performance, the operating voltage was set to 2.6 kV, where the rate of afterpulses is very large (see Fig. 9). The average current density was $\sim$ 150 nA/cm. During 10 days of exposure, which resulted in a total collected charge of 70 $\frac{mC}{cm \cdot wire}$, we have not observed either dark current or changes in operating current. Further electron beam tests revealed no change in efficiency for both irradiated wires (see Fig. 1). The appearance of some wire specimens after exposure in Ar/CF_4 was slightly more black than that of new ones, however, SEM imaging revealed clean Au anode wire surfaces, with negligible amount of C found at 5 kV SEM voltage. The EDX spectrum at 20 kV shows only gold (see Fig. 2). EDX analysis of irradiated cathode surfaces revealed some traces of fluorocarbon deposits (see Fig. 3).

From our results so far, no loss in performance of aluminum proportional chambers operated with Ar/CF_4 (70:30) without water has been observed up to collected charge $\sim$ 70 $\frac{mC}{cm \cdot wire}$.

2 Aging in a CF_4/CH_4(90:10) gas mixture

In wire chamber operation, many studies have demonstrated excellent aging properties, up to 10 $\frac{C}{cm \cdot wire}$, of CF_4/iC_4H_{10} (80:20) avalanches, which also has an ability to etch silicon-based and hydrocarbon deposits from previously aged gold-plated wires [25]. Aging studies have also been performed with a CF_4/CH_4 (90:10) mixture and no deterioration was found up to 1.9 $\frac{C}{cm \cdot wire}$ [26]. At the same time, heavy carbonaceous deposits (without incorporation of CF_x fragments into the polymer) were formed on the gold-plated wires irradiated in the mixtures CF_4/iC_4H_{10} (95:5), CF_4/iC_4H_{10} (20:80) and CF_4/C_2H_4 (95:5) [18]. Clear rapid aging effects were also seen in honeycomb drift chambers operated with $Ar/CF_4/CH_4$ (74:20:6) and CF_4/CH_4 (80:20) mixtures in high-rate hadronic environments [6, 8, 9]. From our results

so far, aging effects were observed in aluminum proportional chambers irradiated with $Ar/CF_4/CH_4$ (74:20:6) and $Ar/CF_4/CH_4$ (67:30:3) mixtures (even with the incorporation of CF_x fragments into the polymer structure). In order to find a link between the divergent results obtained in CF_4/hydrocarbon and $Ar/CF_4/CH_4$ mixtures, we performed radiation tests with CF_4/CH_4 (90:10) and CF_4/CH_4 (80:20) gases in the high-rate HERA-B environment.

Fig. 5a shows tube chamber efficiency for CF_4/CH_4 (90:10) and CF_4/CH_4 (80:20) gases, measured in an electron beam before the aging run, as a function of high voltage. Aging studies with CF_4/CH_4 (90:10) + 600 ppm H_2O mixture have been carried out on a set of two chamber cells N1,N2 connected in a serial gas flow. We have employed the flow rate of 1.5 l/hour. Wires were operated at a high voltage of 3.0 kV, which led to an average current density of 200 nA/cm. The total accumulated charge at the end of the run was $\sim 370\ \frac{mC}{cm \cdot wire}$. After the aging test, scanning along the wires in an electron beam showed no loss in performance for most wire specimens, except a region (~ 4 cm) of wire N2 near one of the chamber endcaps, where a large efficiency drop was found (see Fig. 4). However, the reason for this inefficiency remained unclear due to technical reasons. Fig. 5b shows SEM imaging of wire N2's central region, placed downstream of the damaged area in the direction of gas flow, where the EDX analysis (at 20 kV SEM voltage) revealed only Au signal. In the EDX spectrum of the irradiated cathode we did not observe any significant layer of deposits on the surface (see Fig. 3).

3 Aging in a CF_4/CH_4(80:20) gas mixture

We have studied the aging properties of a CF_4/CH_4(80:20) mixture in two ways: 1) with 600 ppm H_2O and 2) without additives.

Initially, radiation tests with a CF_4/CH_4(80:20) + 600 ppm H_2O mixture were carried out on a set of three chamber cells - N7,N8,N9, connected in a serial gas flow. We have employed a flow rate of 1.5 l/h. Wires were operated at a high voltage of 3.0 kV, which led to an average current density ~ 150 nA/cm. During one month of exposure, which resulted in a collected charge of $\sim 170\ \frac{mC}{cm \cdot wire}$, we have not observed either dark current or changes in operating current. However, scanning along the wires in an electron beam revealed a loss in efficiency for all irradiated wires. Fig. 6 shows efficiency profiles for wires N7,N8,N9 after an accumulated charge $\sim 170\ \frac{mC}{cm \cdot wire}$. It is of special interest that aging effects in a CF_4/CH_4(80:20) + 600 ppm H_2O

mixture only slightly increases in the direction of the serial gas flow (from wire N7 to N9) and are much more severe in the center of the wires (x $\sim$ 250 cm), where the radiation intensity was the highest (see Fig. 6).

At the conclusion of the tests anode wires and cathodes were disassembled from the chamber and inspected with SEM and EDX. Fig. 7 shows micrographs of wire N8 at 20 kV and 5 kV SEM voltages. While in the EDX spectrum at 20 kV there is no significant concentration of elements other than the wire material, the EDX spectrum at 5 kV is dominated by an intense C peak (see Fig. 7). However, these deposits are far less substantial than those observed in the $Ar/CF_4/CH_4$ mixture. Only negligible amounts of C, O and F were identified on irradiated cathodes after exposure in a CF_4/CH_4(80:20) + 600 ppm H_2O mixture (see Fig. 3).

In the second run, all polyamid tubes were exchanged for stainless steel ones, and aging studies with a CF_4/CH_4(80:20) mixture without water were performed on another set of the wires - N11,N12,N13. All operating conditions were kept as in the previous run (gas flow - 1.5 l/hour, high voltage - 3.0 kV). Due to the smaller radiation intensity for wires N11,N12,N13, the average current density was lower $\sim$ 100 nA/cm. During exposure, we have not noticed any operational degradation of the wire performance. After 10 days of irradiation, which resulted in a total collected charge of $\sim$ 40 $\frac{mC}{cm \cdot wire}$, studies in an electron beam have shown that all three wires are fully efficient.

In contrast to the $Ar/CF_4/CH_4$ mixture, aging tests of aluminum proportional chambers filled with CF_4/CH_4 (90:10) and CF_4/CH_4 (80:20) did not show either a rapid gain reduction at the level of accumulated charges $\sim$ 30-100 $\frac{mC}{cm \cdot wire}$, or the appearance of the dark current. No dependence of lifetime on water addition and size of irradiation area was observed for CF_4/CH_4 gases.

Using CF_4/CH_4 (90:10)+ 600 ppm H_2O, a stable lifetime of up to 370 $\frac{mC}{cm \cdot wire}$ was achieved for two wires, except for one wire specimen ($\sim$ 4 cm out of 50 cm), where a significant gain reduction was detected. The origin of this aging is not understood.

Using CF_4/CH_4 (80:20)+ 600 ppm H_2O, a gain reduction was observed after a radiation dose of 170 $\frac{mC}{cm \cdot wire}$ for all three irradiated wires. SEM analysis confirmed the presence of a thin layer of a carbonaceous deposit on the anode wires. At the same time, no loss in performance was observed for three wires operated with a CF_4/CH_4 (80:20) mixture without water up to 40 $\frac{mC}{cm \cdot wire}$.

4 Aging in an $Ar/CF_4/CH_4$ (74:20:6) gas mixture

From our results reported in [10], rapid aging effects were observed during irradiation of the tube chamber filled with an $Ar/CF_4/CH_4$ (74:20:6) mixture in a 100 MeV α-beam of the cyclotron in the research center "Forschungszentrum Karlsruhe GmbH". Therefore, this mixture was clearly ruled out for the use in the muon detector on the basis of it's aging properties. However, radiation tests with $Ar/CF_4/CH_4$ (74:20:6) were also performed in the HERA-B environment. As operating parameters were not kept constant during the aging run, these results can be only used for a qualitative picture of the aging behavior of $Ar/CF_4/CH_4$ (74:20:6) mixture under high-rate irradiation.

The experimental setup and operating conditions during the aging studies were the following. Tube chamber with 16 drift cells and a cross cell exactly as for the production version, but of a shorter length of 50 cm, was placed between the electromagnetic calorimeter and muon absorber, as shown in Fig. **??**. A pre-mixed gas was transported by a 150 m stainless steel tube followed by a polyamid tube connected directly to the chamber inlet. However, the chamber outlet was not connected to a gas chromatograph, which left us unable to measure the level of species (N_2, O_2 H_2O) in the effluent gas stream. During the aging run, the chamber was operated at several high voltages in the range 2.3 - 2.5 kV (see Fig. 9), which led to average currents of 80-300 μA, measured from 16 anode wires. The gas flow also varied during the tests from 3 l/h up to 15 l/h. By monitoring the chamber current the average collected charge was determined. Similar to the performance of aged wires in an $Ar/CF_4/CH_4$ (67:30:3) mixture, the 'switch-on' current behavior and the dependence of the current on the gas flow rate also appeared during operation with $Ar/CF_4/CH_4$ (74:20:6) in HERA-B, indicating the onset of aging effects.

It should also be noted that in order to study the dependence of the anode current on the gas flow, chamber flushing was stopped a few times for intervals of approximately 20 minutes. Irradiation of the chamber was halted when the average collected charge for the wires had reached approximately 200 $\frac{mC}{cm \cdot wire}$. When, at the conclusion of the tests, the chamber was opened for inspection, surface deposits were found on the anode wires. Fig. 8 shows typical micrographs of deposits for two wire specimens. EDX analysis of these wires revealed the presence of a polymer coating, consisting of C, F (and most probably O) elements.

It is of special interest that, as in our previous studies using a

100 MeV α-beam with an $Ar/CF_4/CH_4$ (74:20:6) mixture and results with $Ar/CF_4/CH_4$ (67:30:3) in the HERA-B environment, these tests also revealed the presence of fluorine in the anode wire deposits.

5 Summary

High energy and luminosity experiments pose a new challenge for the construction and operation of large area gaseous detectors. The HERA-B muon system, with a total gas volume of 8 m^3, puts rather stringent constraints on the gaseous medium to be used: extremely low aging, high resistance to sparking, good transport properties (high drift velocity v_d, convenient operating electric field E/p), good chemical properties (non-flammable, non-poisonous). Under these constraints only a limited choice of gases can be used and, moreover, the new generation of experiments demand a higher radiation hardness than available from conventional mixtures ($\leq 1 \frac{C}{cm \cdot wire}$).

About twenty years ago, CF_4 was proposed as a most attractive candidate for the wire chamber operation in high rate environments. This is primarily due to the high drift velocity, high primary ionization density and low electron diffusion of CF_4 [27, 28, 29, 30]. Many studies also have demonstrated an excellent aging performance of several CF_4-based mixtures, which suppress aging effects up to an exposure of $\sim$ 10 $\frac{C}{cm \cdot wire}$ [31, 32]. Within the broad spectrum of gases, there are no mixtures without CF_4 that are able to tolerate such radiation doses. From the viewpoint of plasma polymerization the CF_4 molecule is an ideal source for a variety of reactive neutral and ionic fragment atoms and molecules formed in either the ground or excited states which are largely responsible for surface reactions in various etching and deposition applications. It is believed that, when CF_4 dissociates in the gaseous discharges into highly reactive CF_x and F radicals, especially the elemental fluorine is very effective in suppressing polymerization in the wire chamber. Actually, in a plasma environment CF_4-based gases are used for both etching and deposition processes, the distinction being made by the gas and its concentration with which CF_4 is mixed [23]. The high radiation load of the HERA-B experiment and the requirement of a fast signal collection within the 96 ns time interval between two consecutive bunch crossings, led us to consider one of the Ar/CF_4-based mixtures: $Ar/CF_4/CH_4$ (74:20:6), $Ar/CF_4/CH_4$ (67:30:3) $Ar/CF_4/CH_4$ (65:30:5) for the muon detector operation.

The aging performance of aluminum proportional chambers has been in-

vestigated for five different CF_4-containing mixtures in three different experimental setups: laboratory conditions (Ru^{106} and Fe^{55} sources), a 100 MeV α-beam and the high-rate HERA-B environment. The size of the irradiation zone varied in the tests from 1 cm up to 500 cm. Some of the results obtained in the framework of these studies have already been published [10]. In the following the summary of aging studies as well as possible application of these results to the construction of a large area gaseous detectors for operation in high rate environments is presented. The effect of added CF_4 on the aging performance of wire chambers and some possible chemical mechanisms in the CF_4-containing gaseous discharges will be discussed in a companion paper [16].

1. The aging rate of aluminum proportional chambers filled with $Ar/CF_4/CH_4$ (74:20:6) and $Ar/CF_4/CH_4$ (67:30:3) mixtures differs by more than two orders of magnitude for laboratory tests with radioactive sources and in the high-rate radiation environments. These results clearly indicate that the aging rate depends on a particular set of operating parameters and, therefore, from the accumulated charge alone it is not possible to combine the data from the different experimental setups into one consistent model. In a view of the aging results presented here it is important to note that the initial stage of radiation tests usually performed in the laboratory may not offer full information, needed to give an estimation about the lifetime of the real detector.

2. Aging effects in tube proportional chambers filled with $Ar/CF_4/CH_4$ (74:20:6), $Ar/CF_4/CH_4$ (67:30:3) mixtures were observed after irradiation in a 100 MeV α-beam and in the high-rate HERA-B environment. For operation in HERA-B the aging behavior of the $Ar/CF_4/CH_4$ (67:30:3) mixture was found to depend on the high voltage and the size of the irradiation area. SEM analysis of the aged anode wires, operated with a gas gain $> 10^4$, revealed a polymer matrix, consisting of C and F elements (H is not detectable). Anode aging was also accompanied by the appearance of a thin layer of polymers on the cathode, consisting of C, F and O. These surface deposits on the electrodes resulted in a gain reduction and in the appearance of a dark current during operation in HERA-B. In contrast to deposits formed at a gas gain $> 10^4$, one of the anode wires operated at a gas amplification factor $< 10^4$ had only trace carbonaceous deposits, without incorporation of F into the polymer structure. Although, addition of H_2O results in the suppression of the polymerization effects in the $Ar/CF_4/CH_4$ (67:30:3) mixture, our results

clearly indicate a problem for the use of $Ar/CF_4/CH_4$ mixture in the muon detector at the HERA-B experiment.

In the wire chamber operation fluorocarbon deposits were usually not observed on the Au/W anode wires [18]. This was mainly attributed to the fact that CF_4 can not polymerize without breaking of the C-F bond. Once fluorine is split off, however, it's ablative effect becomes predominant. From the results of tube chamber operation with $Ar/CF_4/CH_4$ (74:20:6) and $Ar/CF_4/CH_4$ (67:30:3) mixtures, it is evident that fluorine may be also incorporated into a polymer matrix on the anode wires. At the same time, different aging performance of CF_4/CH_4 (90:10) and CF_4/CH_4 (80:20) gases, where fluorine was not detected on the wires lead us to the conclusion, that the aging properties can not be solely explained on the basis of the molecule ratios of the gases, without taking into account the actual discharge conditions. The change in operating parameters (gas gain, area of irradiation, gas flow) could be one of the possible explanations of the difference in aging behavior between $Ar/CF_4/CH_4$ (67:30:3) and CF_4/CH_4 (90:10), which have nearly identical ratio of CF_4/CH_4 molecules in the mixture.

Strong dependence of the aging rate on high voltage and the size of the irradiation area has been also reported in [19, 20]. Since presumably the high voltage is not the physical quantity which is directly responsible for aging in wire chambers, the avalanche-related aging effects can be classified as depending on both the total charge of the avalanche (avalanche size) and on the gas amplification, which is related to the mean electron energy in the avalanche and, therefore, to different excitation and ionization phenomena. Thus, the increase in high voltage could either result in a significantly larger pulse charges, especially if self-quenching streamers appears, or in discharges (glow discharges or sparks). The increase in high voltage could also initiate the production of new reactive species, or produce them at a much larger rates thus promoting the polymer formation.

The main principles of traditional plasma chemistry (low pressure, rf) are generally used to predict chemical reactions in the wire avalanches [18, 34, 35]. The dependence of the polymer formation on the energy input level is well established in plasma polymerization. The 'fragmentation' of molecules in a plasma is highly dependent on the structure of the starting material and the discharge conditions. Nearly all organic compounds regardless of their chemical nature can be polymerized. Particularly, polymers consisting of C and F elements were produced by the polymerization of the etching gas

CF_4 [36, 37, 39]. In general, considerable fragmentation of the initial gas or rearrangement of atoms occurs in plasma and the extent of the process and the dominating mechanisms vary with the type of gas and the discharge conditions. Because of this aspect, the structure of plasma polymers formed from the same monomer is highly dependent on the actual conditions of plasma polymerization, in particular, the energy input level, the size (cross-sectional area) of a tube or reactor and even on the position within the reactor [23].

The experimental data presented here indicate that the balance between polymer formation and ablation in the wire avalanches could depend not only on the chemical nature of the gas mixture, but also on the discharge conditions, particularly the energy density. The trends found in these studies require to simulate the final radiation conditions of the experiment as well as possible in order to choose the mixture for operation in the high-rate environments.

3. Recent studies have shown also the dependence of aging properties on the size of the irradiation area, in particular, an increase of the aging rate in the direction of the serial gas flow [19]. Another example is that developments of anode aging and Malter effects in honeycomb drift chambers were not so pronounced in short $\sim 10\ cm$ chambers as in long $\sim 100\ cm$ chambers [9]. These observations seem to be the most critical when trying to extrapolate the aging behavior from small to large areas of irradiation. In a naive approach these effects can be explained as follows. Upon the repeated gaseous discharges, polymer-forming species are produced and diffuse in the direction of the gas flow. During this diffusion, some of the long-lived radicals may migrate and react with active polymer fragments even outside the avalanche region, thus resulting in a further growing of the polymerized chains.

In plasma polymerization of CF_4 the degree of conversion of the starting material was found to be a monotonic function of the residence time in the discharge zone [38]. However, the extent to which this result can be applied to the wire chamber operation, where the production of reactive species is mostly confined to a small region ($\sim 50\ \mu m$) near the anode wire, is not clearly understood. It is important to note that due to the increased aging effects in the direction of the gas flow it is worthwhile to avoid gas systems, that supplies many chambers in a serial flow.

4. The hydrocarbon free gases are much more resistant to aging than gases with hydrocarbons, especially for operation in a high-rate radiation environment. No loss in performance of the aluminum chambers was observed

in the hydrocarbon free gases after an accumulated charge of 700 $\frac{mC}{cm \cdot wire}$ in an $Ar/CF_4/CO_2$ (65:30:5) + 1000 ppm H_2O and of 70 $\frac{mC}{cm \cdot wire}$ in an Ar/CF_4 (70:30) mixtures in the real HERA-B environment.

5. In order to successfully operate gaseous detectors at severe radiation conditions, one should certify the gas purity and chemical reactivity of the various materials in order to avoid the presence of 'bad' molecules in contact with the gas system. Furthermore, the effects of the cathode materials on the aging performance should be investigated, especially for CF_4-containing mixtures, since polymers were found on the non-gold plated tungsten wires, after exposure in a strongly etching mixture CF_4/iC_4H_{10} (80:20) [18]. A detailed summary of the influence of commonly used materials on aging properties may be found in [35, 40].

6. Since the aging effects are of a statistical nature, it is of primary importance that the radiation tests should be carried out on a set of wires irradiated under identical conditions. Such a study will allow for the exclusion of statistical fluctuations in the aging performance and provide a reliable estimation about the detector lifetime.

Finally, many chemical processes are expected to occur simultaneously in the gaseous discharges surrounding the wire and therefore a quantitative description of aging effects, which would require as a minimum, a detailed analysis of all gas phase and gas surface reaction products, is not possible. In addition, many of the reactions may be extremely sensitive to the nature and purity of the gas mixture, different additives and trace contaminants, construction materials, the actual geometry of the electrodes, the gas flow, the irradiation intensity, the size of the irradiation area, the particle species... Since, the present state of knowledge does not allow one to formulate a complete set of recommendations of how to prevent the aging effects in wire chambers, it is important to study the aging performance of the mixture in the conditions as closely as possible to real ones. In a view of the aging results discussed here, one can also see that in wire chamber operation, the presence of large amounts of CF_4 in the mixture does not necessarily ensure good aging performance.

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Figure 1: Efficiency profiles along wires N15,N16 after an accumulated charge $\sim 70\ \frac{mC}{cm \cdot wire}$ in Ar/CF_4 (70:30) mixture. For comparison, efficiency for reference wire N14 is also shown. (Measurements were performed at high voltage 2.4 kV with $Ar/CF_4/CH_4$ (67:30:3) mixture).

Figure 2: SEM micrographs of wire N16, irradiated in an Ar/CF_4(70:30) mixture up to an accumulated charge $\sim 70\ \frac{mC}{cm \cdot wire}$, show the different 'EDX' sensitivity at 20 kV and 5 kV.

Figure 3: EDX spectroscopy of Al cathodes, irradiated in the mixtures: Ar/CF_4 (70:30), CF_4/CH_4(90:10) + 600 ppm H_2O, CF_4/CH_4(80:20) + 600 ppm H_2O.

Figure 4: Efficiency profiles along wires N1,N2 measured in an electron beam, after an accumulated charge of $\sim 370\ \frac{mC}{cm \cdot wire}$ in an CF_4/CH_4 (90:10) + 600 ppm H_2O mixture. These results are to be compared with efficiency of reference wire (N3) $\geq$ 99 % at 2.9 kV.

Figure 5: a) Tube chamber efficiency as a function of high voltage; b) SEM micrograph of wire N2 central region. This region was subjected to a radiation dose of $\sim 370\ \frac{mC}{cm \cdot wire}$ in an CF_4/CH_4 (90:10) + 600 ppm H_2O mixture. EDX analysis revealed only Au signal.

Figure 6: Efficiency profile along wires (N7,N8,N9), measured in an electron beam, after an accumulated charge $\sim 170\ \frac{mC}{cm \cdot wire}$ in an CF_4/CH_4(80:20) + 600 ppm H_2O. These results are to be compared with efficiency of reference wire (N10) $\geq$ 99 % at 2.9 kV.

Figure 7: SEM micrographs of wire N8, irradiated in an CF_4/CH_4(80:20) + 600 ppm H_2O mixture up to an accumulated charge of $\sim 170\ \frac{mC}{cm \cdot wire}$, show the different EDX sensitivity at 20 kV and 5 kV.

Figure 8: SEM micrographs of two specimens, taken from different chamber wires, after irradiation in an $Ar/CF_4/CH_4$ (74:20:6) mixture. In the EDX spectrum, lines corresponding to C, F (and most probably O) are detected.

Figure 9: a) Tube chamber efficiency as a function of high voltage; b) Singles counting rate as a function of high voltage.

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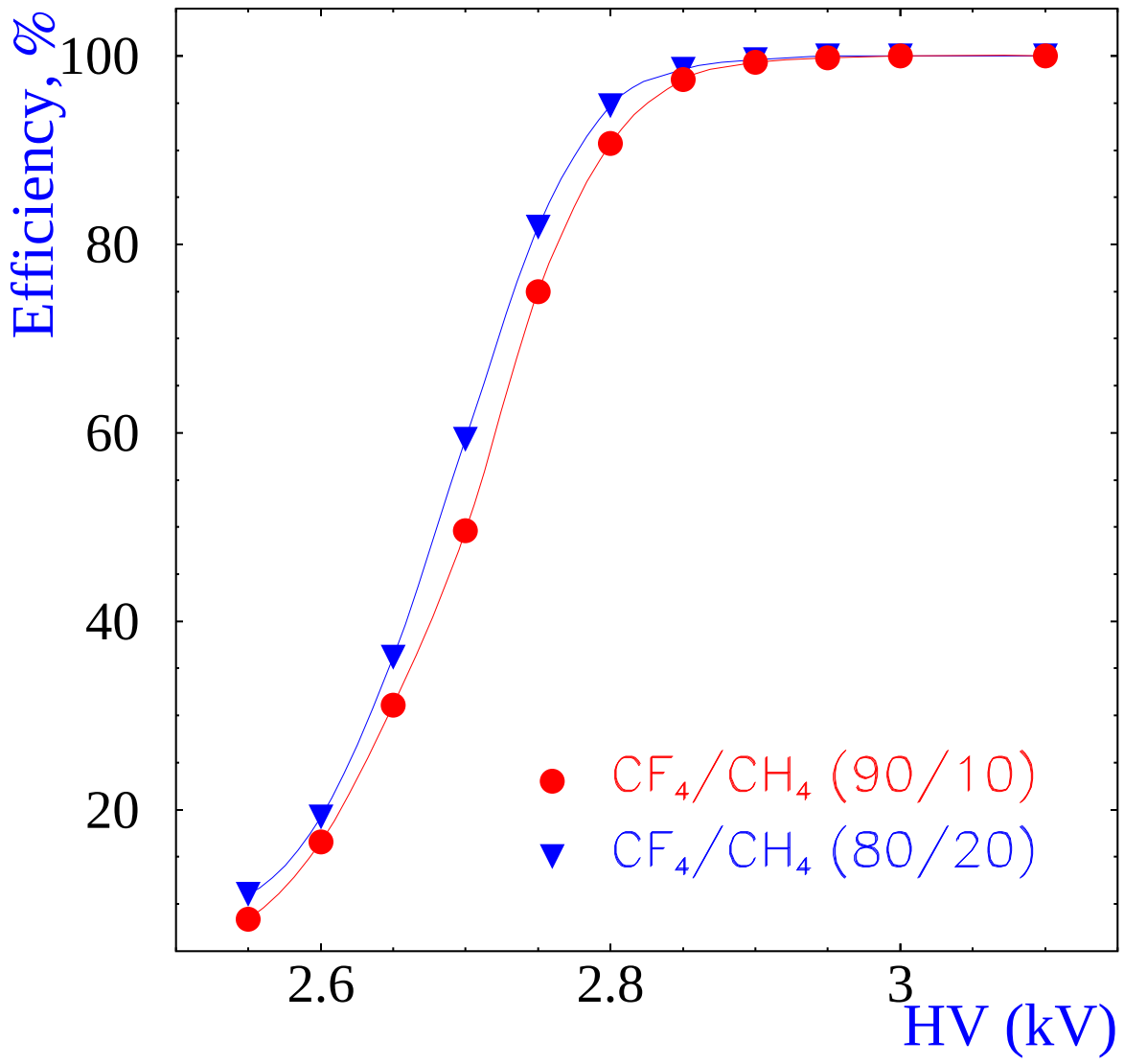
Efficiency, %
100
80
60
40
20
2.6
2.8
3
HV (kV)
CF4/CH4 (90/10)
CF4/CH4 (80/20)

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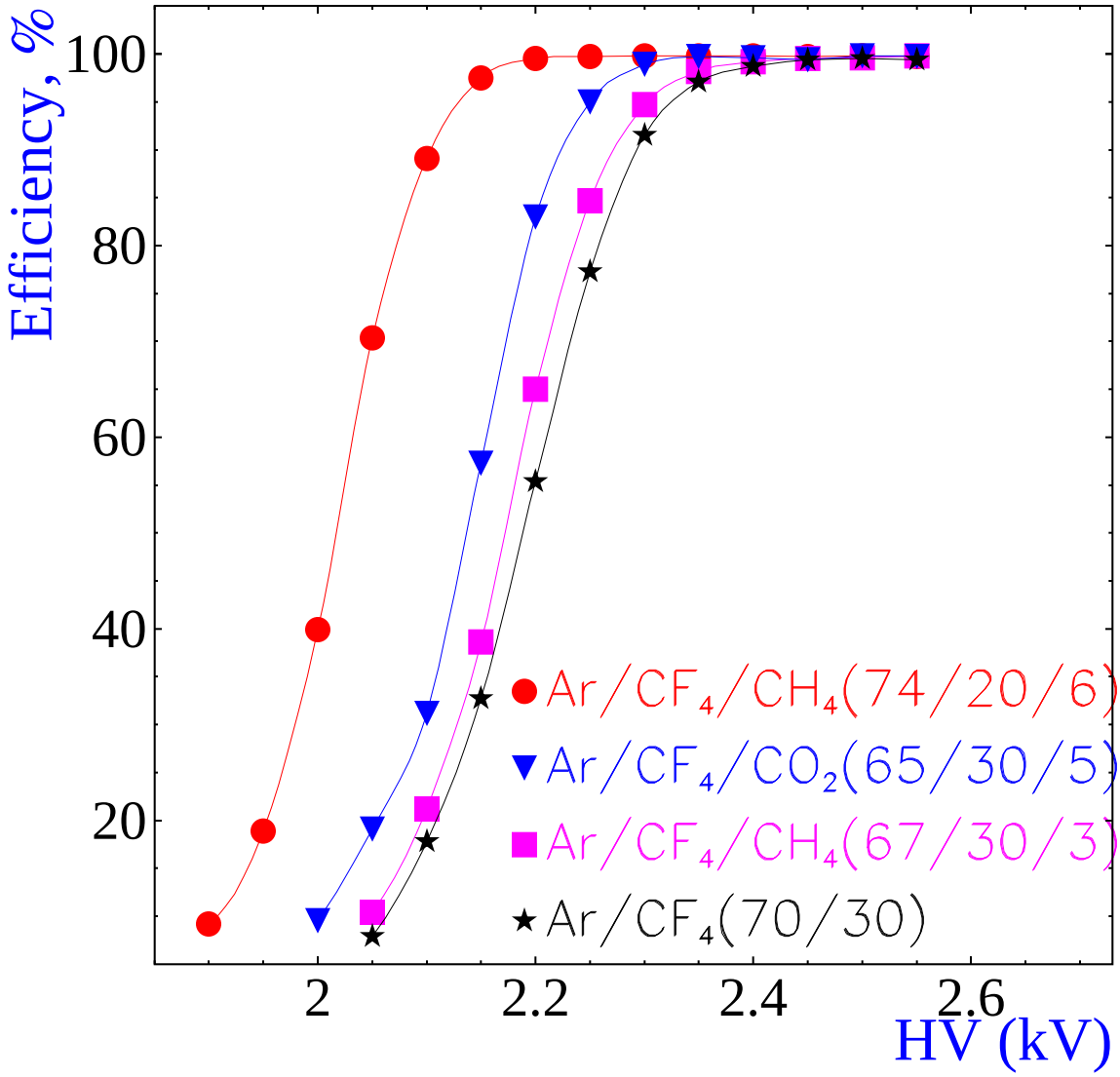
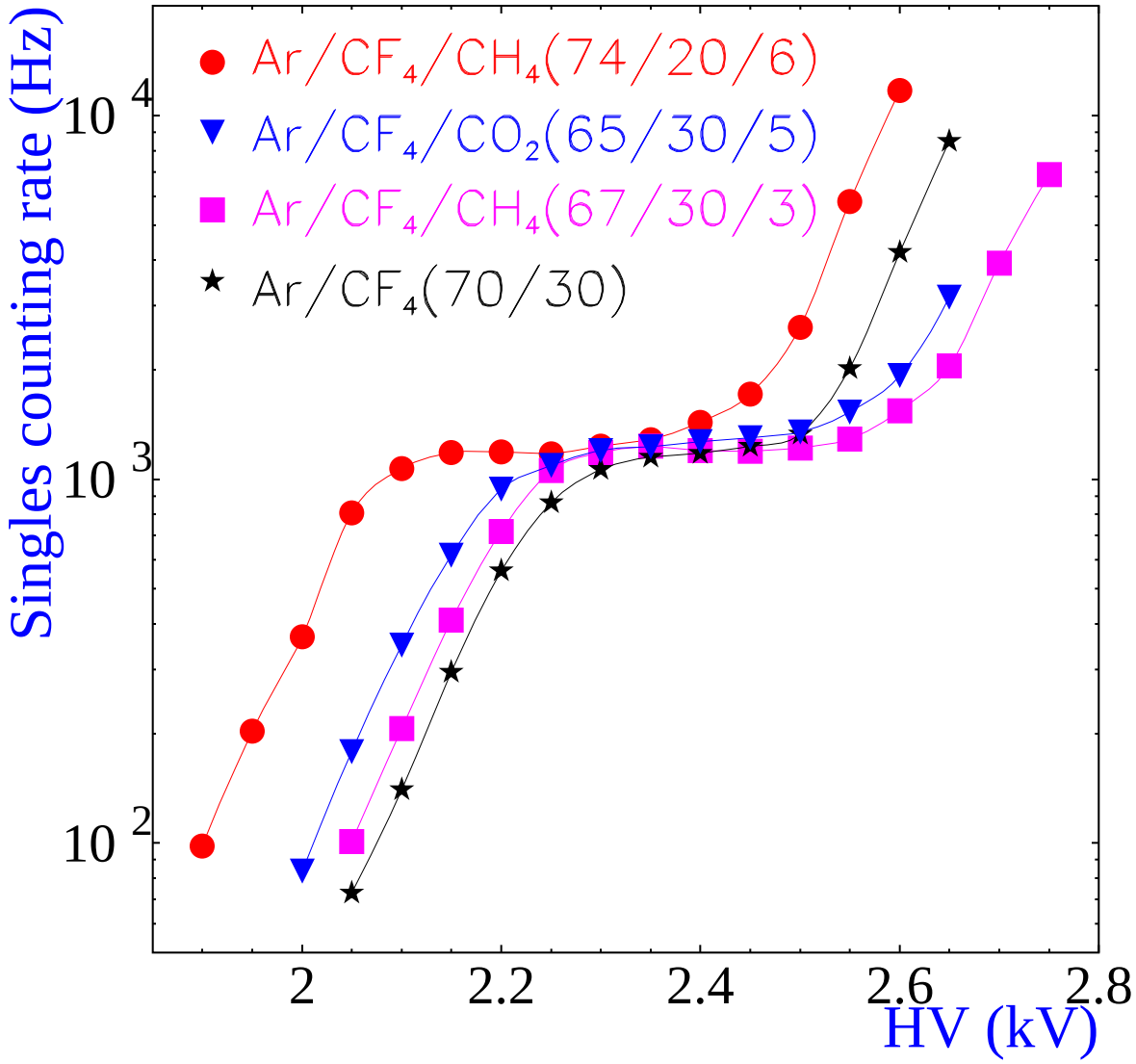

Efficiency, %
100
80
60
40
20
2
2.2
2.4
2.6
HV (kV)
Ar/CF4/CH4(74/20/6)
Ar/CF4/CO2(65/30/5)
Ar/CF4/CH4(67/30/3)
Ar/CF4(70/30)


Singles counting rate (Hz)
10 4
10 3
10 2
Ar/CF4/CH4(74/20/6)
Ar/CF4/CO2(65/30/5)
Ar/CF4/CH4(67/30/3)
Ar/CF4(70/30)
2
2.2
2.4
2.6
2.8
HV (kV)